

Methods – Program Design

Purpose and Design

Historical DRBC monitoring programs have been designed for very specific purposes, such as the 1987 and 1999 bacteria surveys for primary contact recreation suitability assessment, or synoptic surveys used for the 305b assessment to determine compliance with water quality standards. The design of the LDMP is different in that the results are expected to be used not only for compliance with standards, but also to create targets for adaptive management of water quality. Such management includes:

- Establishment of baseline EWQ for future comparison;
- Setting targets for maintenance of water quality where standards are met;
- Setting targets for improvement of water quality where standards are not met;
- Setting geographic and water quality priorities to meet the targets; and
- Monitoring long-term so that DRBC can consistently perform its 305b assessment, monitor trends, prioritize agency management activities, and assess effectiveness of strategy implementation.

In order to meet all of the above purposes, the design was created in order to answer straightforward but difficult questions about the Lower Delaware:

- How does water quality change from the Delaware Water Gap to Trenton?
- Which tributaries produce such changes?
- Where should limited restoration or protection resources be devoted for most water quality benefit?

This monitoring and management approach assumes that each river Interstate Control Point integrates water quality of its upstream tributary drainage. Comparing water quality at each river site to its neighboring sites segments the river and enables identification of tributary impacts within each segment. The design facilitates water quality standard compliance assessment. It also forms a longitudinal analysis template that allows for evaluation of water quality changes from upstream to downstream. Using the control point approach, the northernmost Portland site represents combined water quality effects from 4,170 square miles of drainage area entering the Lower Delaware. Similarly, the southernmost Trenton site represents combined water quality exported from the 6,780 square mile drainage area to the estuary and bay. In between, Boundary Control Points represent water quality being exported from each watershed to exert influence upon water quality of the river, which in turn is monitored at the nearest downstream Interstate Control Point. The key to the method is river segmentation small enough to be manageable, site-specific targets at input and output Interstate Control Points, and targets at Boundary Control Points contributing to each segment. Together these enable longitudinal comparison of water quality changes. Given sufficient data, water quality models can be directly assembled from this design to assess a variety of water quality management scenarios.

Methods - Tributary Watershed Analysis

Monitoring designers listed and located all 53 named tributaries, 55 potential river monitoring sites located upstream and downstream of each tributary confluence, and all water withdrawal and waste discharge points. Biweekly monitoring of such a list would be too expensive, so it was necessary to pare the list to an affordable yet effective set of monitoring locations. Tributary watershed analysis was the first step in reducing the list of candidate sites.

Major tributaries were determined by frequency analysis of tributary watershed area, with those greater than 29 sq. mi. comprising 85% of the Delaware River's drainage area between Hancock and Trenton. **Figure 2** displays results of the analysis. There are 9 major tributary watersheds within the study area. New Jersey tributaries are the Paulins Kill, Pequest, Pohatcong, and Musconetcong. Pennsylvania tributaries are the Lehigh, Tohickon, Bushkill, Martins, and Cooks. BCP sites were established near the mouth of each major tributary. Major tributaries located just outside the boundary of the study area include Brodhead Creek in Pennsylvania (upstream) and Assunpink Creek in New Jersey (downstream).

Of the remaining 44 named 'minor' tributaries of less than 29 square miles watershed area, the LDMP established a BCP on 6 due to state antidegradation status or inclusion in the Lower Delaware Wild and Scenic designation as of 2001. These included Pidcock, Paunacussing, and Tinicum Creeks in Pennsylvania, and Nishisakawick, Wickecheoke, and Lockatong Creeks in New Jersey. Some of the remaining 38 tributaries were monitored occasionally, but not frequently enough for definition of EWQ.

Canals parallel to the river capture some tributaries. The Delaware Canal in PA receives some Lehigh River and Pidcock Creek water. Delaware Canal water spills into the Delaware River at several locations. The Delaware & Raritan Canal in NJ is an out-of-basin water supply diversion from the Delaware River to north-central NJ. The D & R Canal captures all but the highest flows of the Wickecheoke and Lockatong Creeks. Canal spillover to the Delaware River is mostly contained by regular maintenance. One large spillway active during low-flow conditions was observed along Swan Creek in Lambertville, NJ. Canal

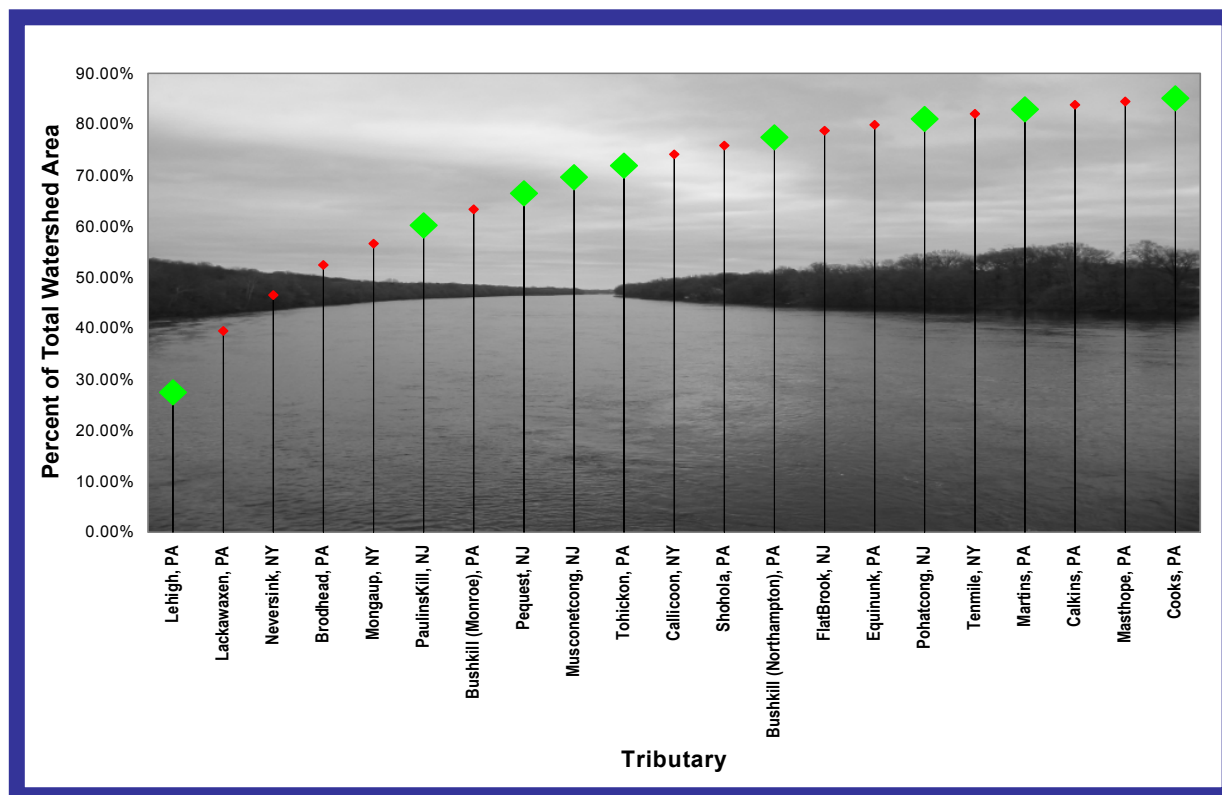


FIGURE 2. Cumulative Percent Watershed Area (top 85%) of Tributaries to the Non-Tidal Delaware River between Hancock, NY and Trenton, NJ. The East and West Branches and Assunpink Creek are located outside of the reach and were excluded from analysis. Large green diamonds represent Lower Delaware tributaries.

effects upon the river are unknown but potentially significant.

Methods – Biological and Habitat Assessment

The Delaware River Basin Commission historically has focused resource protection efforts upon traditional chemical water quality monitoring, which proved very effective at reducing impacts created by point sources of pollution. In the 1990's the basin states began to use a more holistic approach to address complex non-point source pollution problems. The basin states instituted monitoring of biological, chemical, physical, and toxics components of ecosystem function and health. Planning and regulatory efforts of the Commission have recently expanded in scope to include not only water chemistry and toxics monitoring as resource assessment and protection tools, but also monitoring of biological communities, habitat conditions, and other physical measures for sustainable protection of biological integrity. DRBC has also recently improved quality assurance practices and data quality. DRBC monitoring programs aim to provide a well-rounded view of water quality conditions in the Delaware River, and provide sufficient data for timely and meaningful management decisions.

The DRBC's Delaware River Biomonitoring Program gathers sufficient physical, chemical, and biological information to serve the following purposes:

- Implement Special Protection Waters regulations for the Upper and Middle Delaware River.
- Define EWQ and implement anti-degradation protection of the Lower Delaware River.
- Develop a Benthic Index of Biological Integrity (B-IBI) for the non-tidal Delaware River.
- Provide biological assessment information for the Delaware River 305B report.
- Increase the base of ecological knowledge of large free-flowing rivers.

The Delaware River Biomonitoring Program conducts an annual survey of benthic macroinvertebrates and habitat along the 200-mile length of the non-tidal Delaware River from Hancock, NY to Trenton, NJ. Beginning in 2001, the data set resulting from numerous annual surveys will be used to create a baseline Benthic Index of Biotic Integrity (B-IBI) for the Delaware River as well as numeric biological criteria in DRBC Water Quality Regulations. A complete and detailed method description may be found in the Delaware River Biomonitoring Program Quality Assurance Project Plan (DRBC 2003).

Macroinvertebrates are collected at each of 25 best-habitat sites on the Delaware River. Pebble counts, velocity measurements, habitat assessments, and instantaneous water quality samples are concurrently collected to characterize the habitat and water quality at the time of sampling. Habitat quality was evaluated at each Delaware River site using an adaptation of the EPA Rapid Bioassessment Protocol habitat methodology (U.S. EPA 1999). Collection occurs during an August to September index period unless flow conditions are unsafe. DRBC biologists collect macroinvertebrates and both DRBC and National Park Service (NPS) biologists collect the other parameters. DRBC biologists or contract laboratory taxonomists perform macroinvertebrate taxonomy and enumeration. DRBC and the EPA Office of Research and Development perform statistical analysis.

Biological data is compiled in the Ecological Data Application System (EDAS) created by TetraTech, Inc. All metrics are calculated in EDAS. Statistical analysis is performed using Analyze-It, a Microsoft Excel add-on program, or SAS. Data is stored at DRBC for organizational use as well as uploaded onto EPA's STORET national water quality database.

Methods – Water Quality and Flow Monitoring

For a detailed description of water quality and flow monitoring methods, see the DRBC Lower Delaware Monitoring Program Quality Assurance Project Plans (2000, 2001, 2002, and 2003). From May to September 2000-2003, DRBC monitored water quality of the Delaware and tributaries. The mission of the Lower Delaware Monitoring Program is to obtain environmental data that:

- Provides water quality data as the basis for a determination of SPW eligibility.
- Establishes targets for anti-degradation protection strategies supporting SPW policies.
- Reports on water quality status and identifies factors to maintain or improve ecological integrity.
- Expands ecological knowledge of the Lower Non-tidal Delaware River.
- Safeguards the health and safety of the river-using public.

Table 2. LDMP Chemical Parameters

General Water Quality & Descriptors

Air Temperature (F and C)
Alkalinity Concentration mg/l
Chloride Concentration mg/l
Discharge (cfs)
Dissolved Oxygen % Saturation – calculated
Dissolved Oxygen Concentration mg/l
Hardness Concentration mg/l
PH
Specific Conductance umhos/cm
Total Dissolved Solids Concentration mg/l
Total Suspended Solids Concentration mg/l
Turbidity Concentration NTU
Water Temperature (F and C)

Nutrients & Primary Production

Ammonia NH₃-N Concentration mg/l
Chlorophyll A Concentration mg/m³
Nitrate NO₃-N Concentration mg/l
Orthophosphate Concentration mg/l
Phytoplankton Biomass (mg/m³) – calculated
Total Nitrogen:Total Phosphorus ratio – calc.
Total Kjeldahl Nitrogen mg/l
Total Nitrogen mg/l*
Total Phosphorus mg/l

Bacteria

E. coli col/100ml
Enterococcus col/100ml
Fecal Coliform col/100ml

The Lower Delaware Monitoring Program consists of routine baseline monitoring of water chemistry. A list of parameters (measured or calculated) is shown in **Table 2**. Sampling was conducted bi-weekly at 9 Delaware River sites and 15 tributary sites listed in Table 1. A total of 10 samples per site per year were collected from 24 sites during the 2000-2003 seasons. A contract laboratory measured nutrient, bacteria, and physical parameters using only U.S. EPA-approved laboratory methods. Field measurements were conducted on site by DRBC staff. Discharge was measured or estimated (Wahl et al. 1995) and calculated pollutant-loading rates were associated with each sample. All data were managed using Microsoft Excel and uploaded into the STORET national database. Statistical tests and checks of extreme data were made using Analyse-It v. 1.68, by Analyse-It Software Ltd., an add-on statistical program for Microsoft Excel. The Lower Delaware Monitoring Program database is available for download at <http://www.state.nj.us/drbc>. The data base includes all data used for this report as well as data from numerous additional Lower Delaware sites excluded from this analysis where the number of the samples was insufficient for statistical comparisons (n<20).

Gage heights were associated with a flow-rating curve specific to each water body. A series of discharge measurements (n>5) were taken over the expected range of flows. With each discharge measurement, the gage

height was recorded so that the measurement could be related to a point on the flow-rating curve. Rating curves were developed using liner regression techniques, and are presented in **Appendix D**. Discharge values generated by the United States Geological Survey (USGS) were used for the Delaware River and

tributaries with USGS stream gages. At sites where the USGS gage is not located at the sampling point but existed elsewhere in the watershed, a discharge value was calculated based on drainage area weighting.

For this report, non-detect values were assigned as $\frac{1}{2}$ the minimum detection limit as long as less than 20% of all values were non-detects. This allowed for representation of low concentrations while avoiding bias of the dataset. If more than 20% of samples were non-detects, data were censored to retain only the reported values, and the frequency of non-detect values was highlighted as a potential water quality indicator for future trend analysis.

Methods – Statistical Analysis

Once data were checked and placed into the Microsoft Excel database, several additional steps were taken using Microsoft Excel and Analyse-It to compute additional parameters and prepare the data set for statistical comparison of ICP and BCP water quality:

1. Site characteristics were encoded to enable water quality comparisons by low vs. high flow; month; time of day; state; physiographic region, riffle vs. pool sites; river vs. tributary sites; and by river mile. Future reports will highlight results of these analyses.
2. Drainage areas were computed and entered.
3. The 100% dissolved oxygen saturation value was computed for each measurement of water temperature, and observed DO was divided by the computed 100% saturation value to produce the DO% Saturation parameter.
4. The TN:TP Ratio parameter was calculated by summing Nitrate, Nitrite, and TKN Concentrations (TKN already includes Ammonia) to arrive at Total Nitrogen (TN) in mg/l. This was divided by Total Phosphorus (TP) in mg/l to arrive at the TN:TP unit-less ratio. N:P ratios are used to determine nutrient limitations and as indicators of reservoir or lake eutrophication. Interpretation of N:P ratios in flowing water is less well-known, and is a subject of current research interest at DRBC.
5. The Phytoplankton Biomass parameter was calculated by multiplying the Chlorophyll A concentration by a coefficient of 67. It is estimated in Standard Methods for the Examination of Water and Wastewater, 20th Ed. (APHA et. al, 1998) that Chlorophyll A comprises 1.5% of phytoplankton biomass by weight (thus, $1/1.5 = 66.667$).
6. Pollutant loading rates were calculated using the formula Concentration (mg/l) x Flow (cfs) x 5.39378 conversion factor = Loading in Lbs/Day (not presented in this report, see data base).
7. To compare pollutant-loading rates between large and small tributaries, the loading in lbs/day per square mile of drainage area was calculated (not presented in this report, see data base).
8. EWQ tables were prepared for each site and reach wide for the entire Lower Delaware River. Each table contains parametric and non-parametric summaries of all parameters measured: included in each table is N; mean; upper and lower 95% confidence limits of the mean; median; and the 10th and 90th percentiles.
9. Data distributions and normality were checked (Shapiro-Wilks test) for every parameter at every site. As a result, mean values are not compared in this report due to non-normality of site-specific data. Only non-parametric comparisons were performed (except for the normally-distributed log-transformed bacteria data).
10. Data transformations were tried for non-normal data, but failed to produce normality. Only fecal coliform, enterococcus, and E. coli bacteria data were invariably normal once log-transformed. Geometric mean values were compared using t-tests and 1-way analysis of variance with multiple comparisons.
11. All other site-specific comparisons were conducted using non-parametric statistical tests, comparing median values using the Mann-Whitney test, which formally tests for a difference between the medians of 2 independent samples. The Mann-Whitney U test, also commonly referred to as the Wilcoxon rank-sum test, is the most powerful (and is often a more powerful) alternative to the independent samples t-test. The confidence interval around the difference between medians is computed using the Hodges-Lehman method, as both samples are measured on a continuous scale.
12. Graphical presentation of the data includes longitudinal plots of constituent concentrations vs. water quality criteria.

Methods – Comparison of Existing Water Quality to Standards

For this study, water quality was compared to the most stringent rules or guidelines available, regardless of jurisdictional boundaries. **Table 3** shows all DRBC, state, or federal criteria that apply to the Lower Delaware River. Use of only the most stringent of these provided a single and uncomplicated assessment perspective that enabled a politically blind determination of how the most stringent criteria are related to EWQ. Such universal application of the most stringent criteria, no matter which government body created such criteria, is not valid assessment according to Clean Water Act objectives (e.g., Pennsylvania criteria are not valid for assessment of New Jersey waters). The state 305B reports should be consulted for such assessments, as criteria are significantly different between jurisdictional boundaries. An example of non-jurisdictional assessment is use of DRBC river criteria to assess the water quality of tributary waters. Where DRBC stream quality objectives are more stringent than state criteria, the DRBC stream quality objectives were used to assess the state tributaries to determine how tributary water quality relates to that of the Delaware River.

Table 3 shows only EWQ parameters with existing quantitative criteria or guidelines. For parameters with no criteria, EWQ targets may serve to provide some protection for resource uses that these parameters affect. EWQ also serves as baseline information for future criteria development by the agencies.

Table 3. DRBC Stream Quality Objectives and State Criteria Used for Determination of Lower Delaware River Eligibility for Special Protection Water Status. BOLD are most stringent criteria used for SPW determination.

Parameter	DRBC Zone 1D	DRBC Zone 1E	PADEP Rules	NJDEP Rules
Classification	Water Supply, Aquatic Life, Recreation	Water Supply, Aquatic Life, Recreation	Warm Water Fishery	Fresh Water 2-Non Tidal
DO mg/l	5.0 24 hr, min 4.0	5.0 24 hr, min 4.0	5.0 24 hr, min 4.0	5.0 24 hr, min 4.0
DO %	n/a	n/a	n/a	n/a
Water Temperature F	Discharge only no ambient	Discharge only no ambient	5/1-15=64, 16-31=72 6/1-15=80, 16-30=84 7/1-31=87 8/1-31=87 9/1-15=84, 16-30=78	Discharge only no ambient
PH	6.0-8.5	6.0-8.5	6.0-9.0	6.5-8.5
TDS mg/l	120; 500 max	266; 500 max	Mo Avg 500; 750 max	500 max
TSS mg/l	n/a	n/a	n/a	40 max
Alkalinity CaCO ₃ mg/l	n/a	n/a	min 20 mg/l	n/a
Turbidity NTU	30-d 20; max 150	30-d 30; max 150	n/a	30-d max 15; max 50
Total Phosphorus P mg/l	n/a	n/a	n/a	0.1 mg/l
Orthophosphate P mg/l	n/a	n/a	n/a	n/a
Chloride mg/l	n/a	n/a	max 250 Public Water Supply	max 250 (human); max 860 (acute bio); max 230 (chronic bio)
Nitrate NO ₃ -N mg/l	n/a	n/a	max 10 PWS	max 10 (human)
Ammonia NH ₃ -N mg/l	n/a	n/a	pH & temp formula	pH and temp formula
Enterococcus colonies/100ml	n/a	n/a	n/a	33 30-d avg; max 61
Fecal Coliform colonies/100ml	200	200	200 30-d avg; 400 max	200 30-d avg; 400 max
E. Coli colonies/100ml	n/a	n/a	n/a	Federal 126 30-d avg
Macroinvertebrates: EPT	Use UPDE mean EWQ = 15.5			
Macroinvertebrates: Diversity	Use UPDE mean EWQ = 3.6			
Macroinvertebrates: HBI				4.0 or below is intolerant
RBP Habitat	RBP habitat score OPTIMAL range			

Results and Discussion

In the evaluation approach description, measurable components or indicators were derived from narrative requirements for SPW designation in DRBC rules. The following sections describe measurable results of DRBC's physical, chemical, and biological monitoring activities. Each indicator is interpreted by the most stringent known criterion and judged for SPW suitability.

Benthic Macroinvertebrates and Habitat

Biological integrity and habitat quality are two directly measurable aspects of ecological condition. Only the first season's results of the Delaware River Biomonitoring Program were available for this evaluation. When DRBC Special Protection Waters rules were enacted in the early 1990's, three biological metric targets were included in the definition of EWQ: Shannon Wiener Diversity; Equitability; and EPT Richness. In the late 1990's, equitability was found to be an unresponsive indicator of changes to biological integrity. DRBC biologists are presently refining a list of macroinvertebrate community metrics that respond best to water quality changes in the Delaware River. Lower Delaware biological diversity and taxonomic richness scores from 2001 were compared with exceptional quality Middle and Upper Delaware River biological targets from DRBC's water quality rules. Healthy macroinvertebrate assemblages score higher in diversity and EPT richness than stressed assemblages. Lower Delaware macroinvertebrate data were also compared with New Jersey's most stringent pollution tolerance criterion (Hilsenhoff Biotic Index score of 4.0). The lower the Hilsenhoff score, the better and less tolerant of pollution is the macroinvertebrate assemblage. Though results are inconclusive due to small sample size, the data are presented below. Delaware River biocriteria development is underway through 2005 or 2006 with assistance from the U.S. EPA.

In terms of habitat quality, desirable and measurable traits were examined, including numerous parameters listed in the U.S. EPA Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers (1999). Not all of the Rapid Bioassessment Protocol's habitat parameters translate well to large rivers, but parameters that do so include substrate heterogeneity and stability; heterogeneous flow and depth regimes, sediment deposition indicators; channel flow status; bank stability and vegetative protection; and overall habitat complexity and cover. Even in low flow periods the Lower Delaware received optimal habitat scores at every site. Such evidence indicates that the Lower Delaware possesses exceptional habitat conditions for aquatic life. These results must be taken in their context, however, as DRBC chooses biological monitoring sites based on presence of best-available river habitat. Where such habitat exists, RBP habitat scores are optimal. Such locations are numerous and well distributed throughout the Lower Delaware. Riffle-pool frequency is a normal 6:1 channel widths or better, a characteristic of free flowing streams not fragmented by dams and channelization. There are known locations where habitat limitations exist, but habitat value has not been fully delineated throughout the reach.

Preliminary benthic macroinvertebrate results suggest that that the biological community of the non-tidal Lower Delaware River is exceptional and appears worthy of Special Protection Waters designation. Lower Delaware benthic community data collected during August-September 2001 compared favorably with existing targets for the Special Protection Waters of the Upper Delaware River. Because biocriteria do not currently exist for the Lower Delaware, the Upper Delaware's most conservative thresholds were used. Results indicate that Special Protection Waters protection is appropriate, since the Lower Delaware River largely scored as well as or better than target values set for waters already so designated.

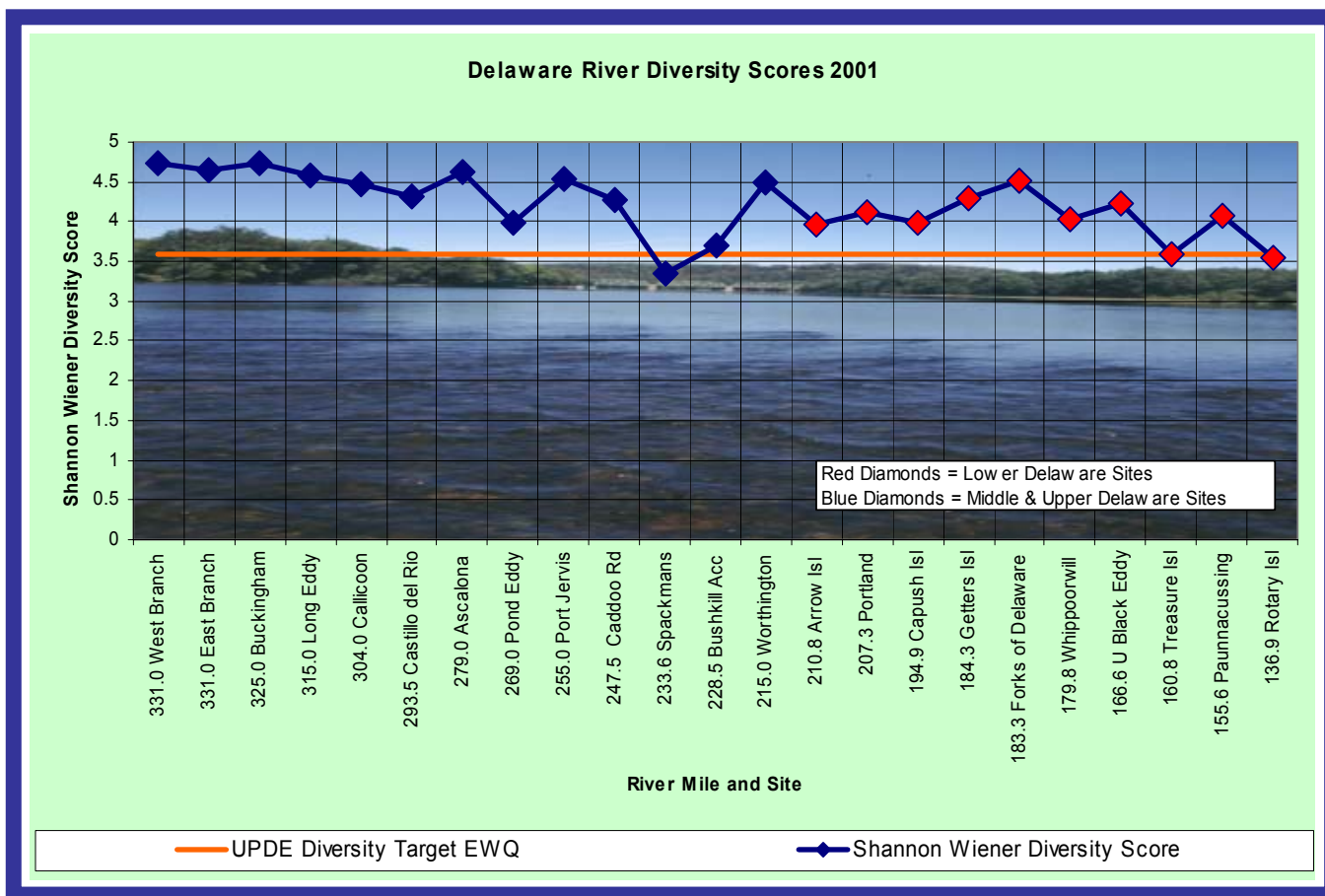


Figure 3. Shannon-Wiener diversity scores for macroinvertebrate samples taken in 2001 from best-habitat riffle sites along 200 miles of the non-tidal Delaware River. Lower Delaware sites are marked by red diamonds, Upper and Middle Delaware sites by blue. The orange line is the diversity biological target set as Existing Water Quality in DRBC water quality rules for the Upper Delaware Scenic and Recreational River.

Figure 3 shows results of biological monitoring using the Shannon-Wiener Index, a measure of diversity of the macroinvertebrate assemblage. Lower Delaware diversity appears low at 2 sites (Trenton and Treasure Island), but those scores that missed the Upper Delaware's mean EWQ diversity target of 3.6 were within 95% confidence limits of the mean. These limited results suggest that the Lower Delaware River possesses a highly diverse macroinvertebrate assemblage, meriting SPW status.

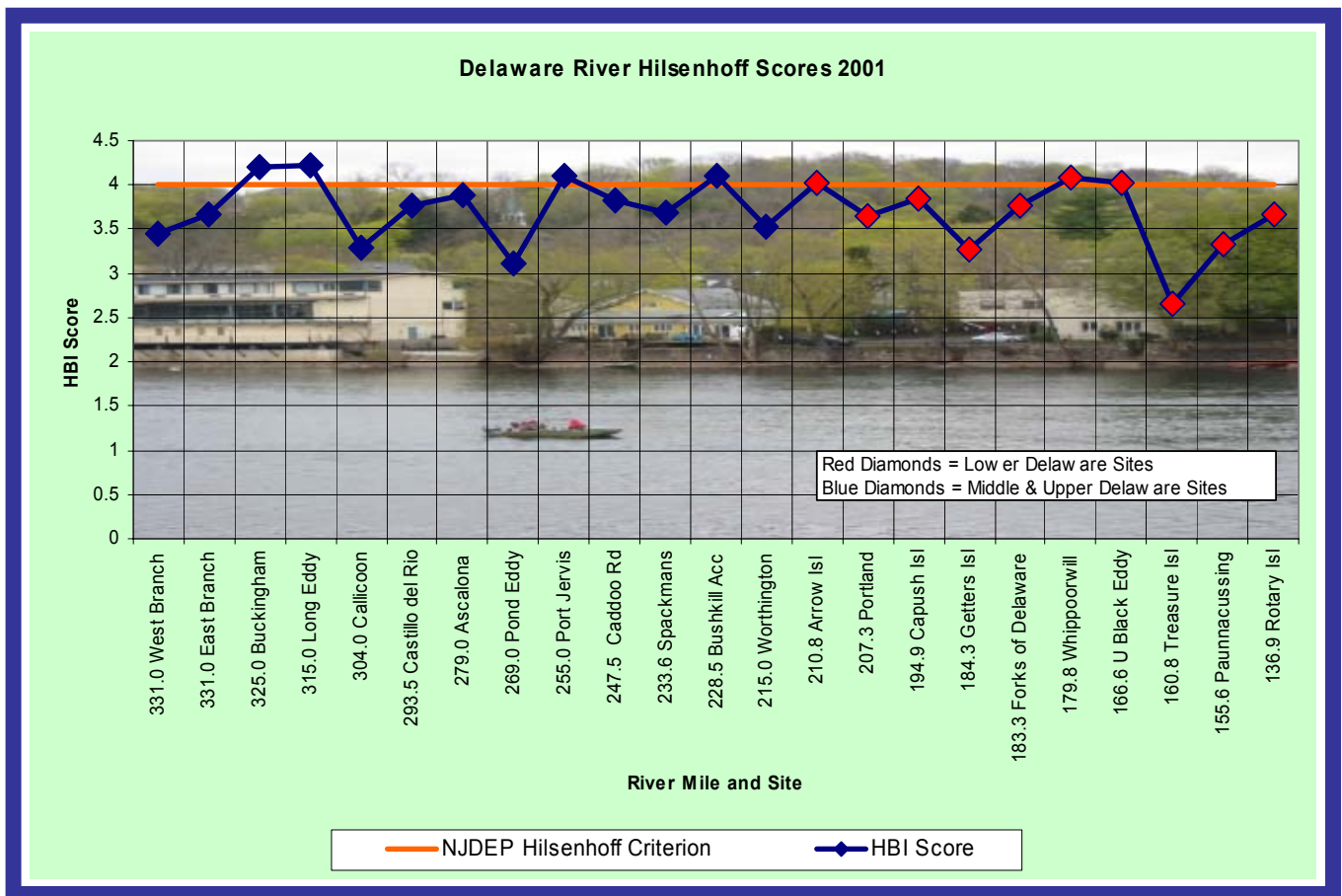


Figure 4. Hilsenhoff Biotic Index scores for samples taken in 2001 along 200 miles of the non-tidal Delaware River. Lower Delaware sites are marked by red diamonds, Upper and Middle Delaware sites by blue. Low Hilsenhoff scores indicate intolerance to pollution and better water quality. The orange line is New Jersey's Hilsenhoff criterion of 4, used to indicate an optimal pollution tolerance score.

The Hilsenhoff Biotic Index value was calculated for each sample and then compared against the strictest criterion. New Jersey's HBI of 4.0 is their threshold for intolerance. **Figure 4** shows that the threshold was met at all but 3 sites (Arrow Island, Whippoorwill Island and Upper Black Eddy). Values above 4.0 still fell under EPA's recommended HBI of 4.5 for definition of intolerant. These very limited data suggest that the Lower Delaware River's benthic macroinvertebrate assemblage is intolerant of pollution, indicates excellent water quality, and merits SPW status.

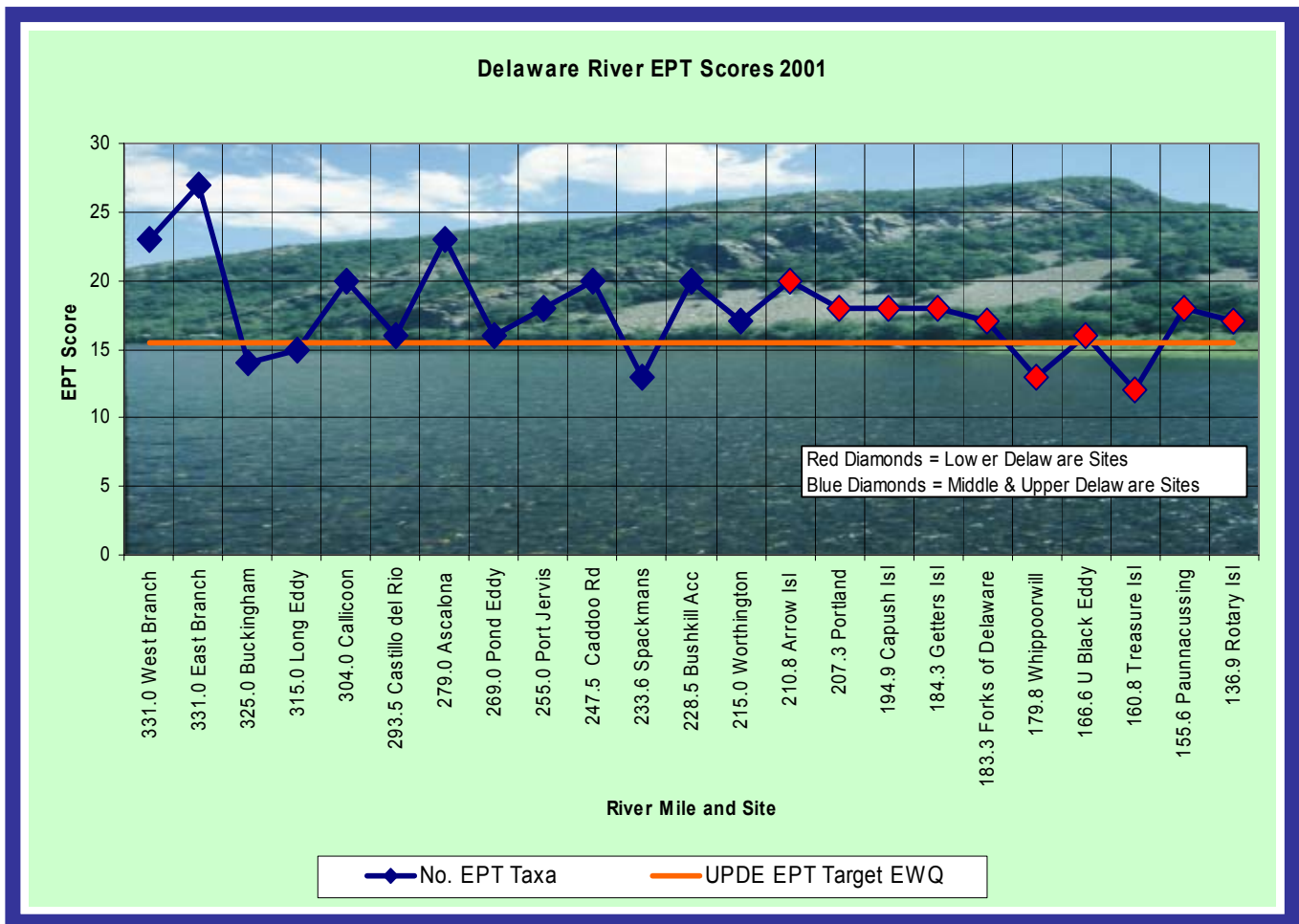


Figure 5. Genus-level EPT Richness scores for samples taken during the August-September 2001 macroinvertebrate survey of 200 miles of the Delaware River. Lower Delaware sites are marked by red diamonds, Upper and Middle Delaware sites by blue. High EPT scores indicate better water quality by virtue of the presence of genera representing three pollution-intolerant orders of aquatic insects: the Ephemeroptera (mayflies); Plecoptera (stoneflies); and Trichoptera (caddisflies). The orange line is the Upper Delaware mean EWQ target EPT richness of 15.5, representing excellent water quality.

At all but 2 sites, the Lower Delaware biological community met the Upper Delaware EWQ target (mean EPT of 15.5) for the presence of Ephemeroptera, Plecoptera, and Trichoptera taxa (EPT), a measure of the presence of the most pollution sensitive taxa in aquatic systems. **Figure 5** shows that those scores that did not meet the threshold (at Treasure Island and Whippoorwill Island) still fell within the 95% confidence limits of the threshold. It will require several more years of data to conclusively verify these results, however, as data above represent only a single macroinvertebrate sample taken from each site. These limited results suggest that the Lower Delaware River benthic macroinvertebrate assemblage is very well represented by pollution intolerant genera; to such a degree that EPT taxa often dominate macroinvertebrate samples taken from the Lower Delaware. This indicates excellent water quality, and supports SPW status.

Hydrologic Regime Represented by Water Quality Data

Figures 6 and 7 show probability plots of flow at Trenton and Belvidere, respectively, for the entire period of record at those USGS gages. Points displayed are flow measured during times water quality samples were taken between May 2000 and September 2003. These give an indication of the flow conditions represented by the data, and the range of flow conditions under which existing water quality was defined. In terms of capturing a wide range of flow conditions, these results show that 2000-2003 data are representative of the historical range of flow in the Delaware River. When interpreting future water quality results versus EWQ targets, comparison would be invalid for samples taken when flow is greater than 40,000 cfs or less than 2,000 cfs at Trenton or Belvidere. Expansion of the data set defining EWQ to include water quality samples taken from higher or lower flows will improve the applicability of resultant EWQ targets.

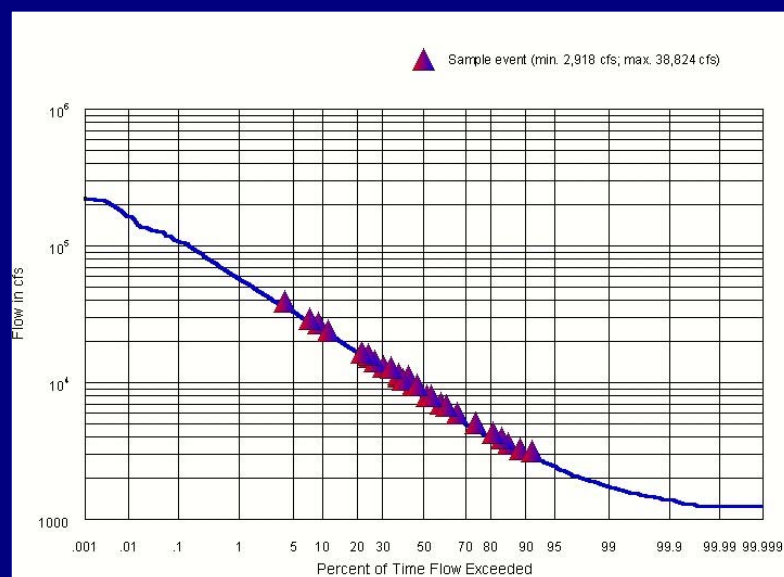


Figure 6. Probability Plot of Delaware River Flow (cfs) at Trenton, NJ. Marks indicate water quality sample events.

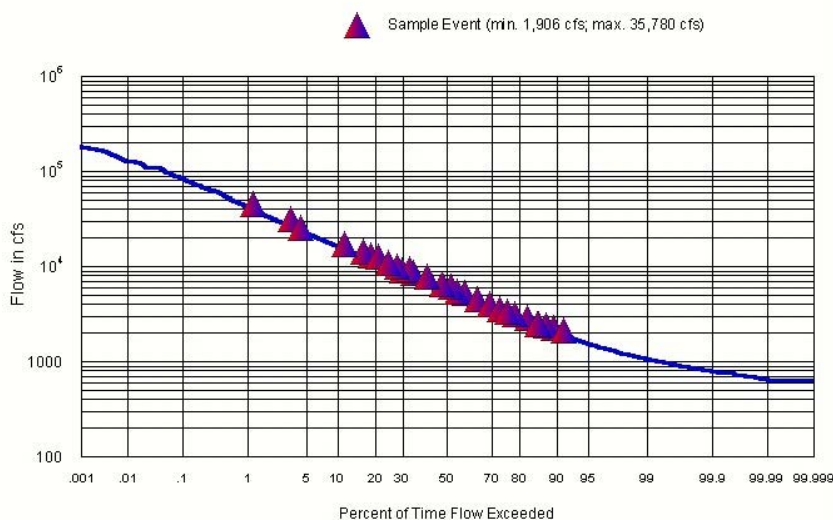


Figure 7. Probability plot of Delaware River flow (cfs) at Belvidere, NJ. Marks indicate water quality sample events.